

Surveying using GPS Precise Point Positioning

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SUMMARY

The technique of Precise Point Positioning (PPP) is a viable alternative to differential methods for precise positioning using Global Navigation Satellite Systems (GNSS). PPP is very cost effective since there is no need for data from local or regional reference stations. Especially in remote areas the logistic is greatly simplified. The PPP method has a potential for centimetre accuracy for static applications and sub-decimeter accuracy for kinematic applications.

PPP-software developed at the Norwegian University of Life Sciences has after a successful verification been used by the Hydrographic Survey of Norway in seafloor mapping since 2003. Based on experiences regarding ease of operation, cost-effectiveness and positional accuracy, a commercial software has been developed by the company Terratec AS.

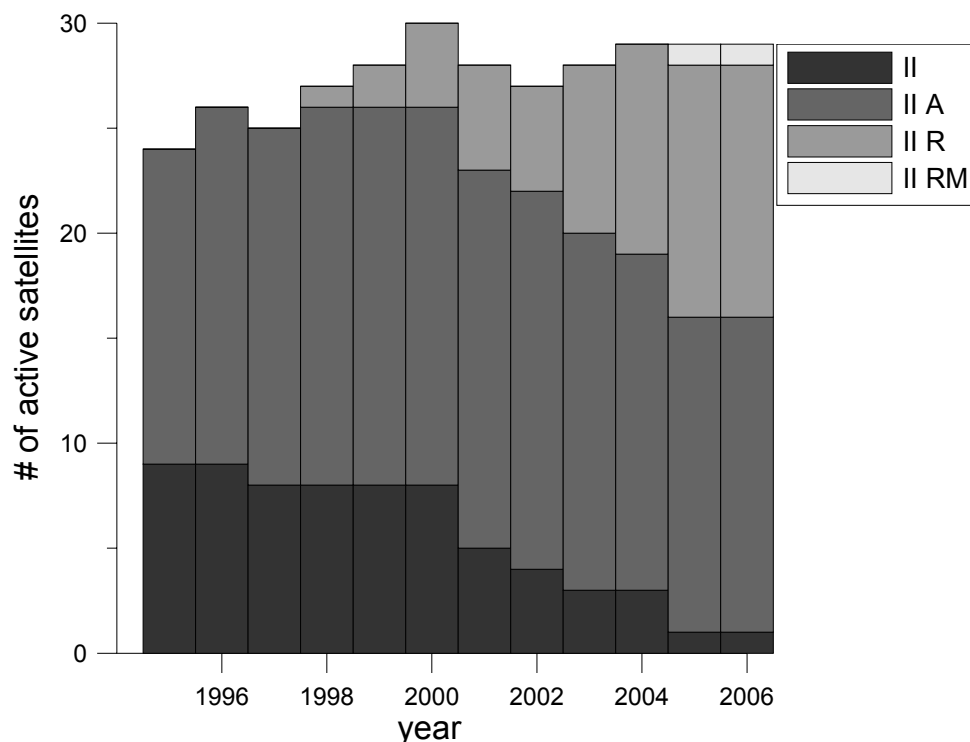
In the presented paper the PPP approach is outlined with emphasis on kinematic measurements. Advantages and drawbacks compared to differential methods are discussed.

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1. INTRODUCTION

Many applications in navigation, land surveying and general geo-referencing have been simplified and made more precise due to the availability of signals from radionavigation satellites. Global Navigation Satellite Systems (GNSS) include military systems like GPS from the United States, GLONASS from Russia, as well as the future civilian system from Europe named GALILEO. It is fair to mention that GPS has been, and still is, the cornerstone of satellite positioning, and the system has been available for civilian use with a remarkably consistency. The first GPS satellite was put into orbit in 1978. Up until 1985 a total of 10 experimental block I satellites were launched. In 1989 the first operational block II satellite was launched, and the system reached full operational capability in 1994. Since then block IIA, IIR and IIRM satellites of different generations have been launched, and at the time of writing 29 GPS satellites are available, see figure. 1.



Figur 1. Generations of GPS satellites in recent years. The graph is based on data from <https://listserv.unb.ca/archives/canspace.html>.

The service made available by GPS for civilian use is called the Standard Positioning Service (SPS) and is based on single frequency pseudorange observations using the C/A-code and the

broadcast navigation message (ICD, 2000). Operating a handheld GPS receiver in locations with favourable satellite availability, coordinates with an accuracy of approximately 3-5 meter in the horizontal and 6-10 meter in the vertical (95%) can be achieved. Main error sources in SPS are atmospheric delay (ionosphere and troposphere), errors in the navigation message (satellite clock corrections and satellite coordinates) and site dependent effects (multipath and measurement noise). It should also be added that weak satellite geometry due to e.g. physical obstructions blocking the satellite signals will further degrade the positional accuracy.

In order to mitigate some of these error sources, differential methods have been developed where one or several reference receivers are operating on sites with known coordinates and where coordinates are estimated relative to the reference receivers. Dependent on the quality of the satellite receivers and sophistication of the observational model, positional accuracies at the meter, sub-meter, decimeter, sub-decimeter, centimeter and finally sub-centimeter level can be achieved. The estimation of coordinates can take form of a post processing where observations from the receivers are brought together to a single computer and processed after survey. Alternatively, data from the reference receivers can be transmitted through a communication link and precise relative coordinates can be estimated in real time. For e.g. navigation and staking out, real-time measurements are a prerequisite, but due operational considerations it seems that real-time systems are more and more preferred also for other survey tasks. In many areas however, reception of reference data via available communication links is difficult/impossible and in some areas there are no permanently operating reference receivers available at all. When using differential methods, a dedicated local reference receiver then has to be operated.

An alternative to differential methods for high accuracy applications is to use observations from one satellite receiver only, but replace the broadcast navigation message with precise post processed values from e.g. the International GNSS Service (IGS). When using dual frequency observations from receivers of geodetic quality and appropriate functional and stochastic models, the potential accuracy is at the centimeter level. The method of precise absolute positioning or Precise Point Positioning (PPP) was first introduced for static applications, Zumberge et al. (1998), but in recent years modified to accommodate kinematic applications as well, see e.g. Kouba & Heroux (2001) and Ovstedal et al (2002). The following sections contains a brief description of PPP, advantages and drawbacks compared to differential methods, some special considerations to take into account when using PPP and some results from a recent project.

2. PRECISE POINT POSITIONING

The model used in PPP can be described as being an extension of the model used by the Standard Positioning Service offered by GPS. Important modifications include the replacement of satellite orbits and satellite clock corrections with more precise estimates from e.g. IGS, the inclusion of the carrier phase as observable and modeling of satellite attitude and site displacement effects, Kouba & Heroux (2001). Given sufficient geometrical strength in the adjustment model, tropospheric effects can be mitigated through estimation of

additional parameters for residual tropospheric zenith delay and ultimately also tropospheric gradients. Factors influencing geometrical strength are the number and distribution of available satellites, elevation cut-off angle, the length of time span with continuous carrier phase observations and dynamics of the satellite receiver. With the availability of dual frequency observations, ionospheric effects can be nearly eliminated through forming ionosphere-free linear combinations of the original observables, see e.g. Hofmann-Wellenhof et al. (2001). When processing single frequency observations the observations have to be corrected for ionospheric effects. Available empirical models include the broadcast Klobuchar ionospheric model (ICD, 2000), post fit Klobuchar ionospheric model estimated by Center for Orbit Determination in Europe (<http://www.aiub.unibe.ch/ionosphere>) and Global Ionospheric Maps available from IGS (<http://igsb.jpl.nasa.gov/components/prods.html>). Due to remaining ionospheric effects when processing observation from single frequency receivers, the positional accuracy will generally not be better than sub-meter, Ovstedal (2002).

Processing a full day of high quality static observation from dual frequency receivers with a state of the art PPP processing software yields positional accuracy at the centimeter level both horizontally and vertically. Shortening the time span of continuous observations and going from static to kinematic mode will decrease the accuracy. For example 6 hours of kinematic observations typically give accuracy at the few centimeter level while 1 hour of observations gives accuracy at the decimeter level.

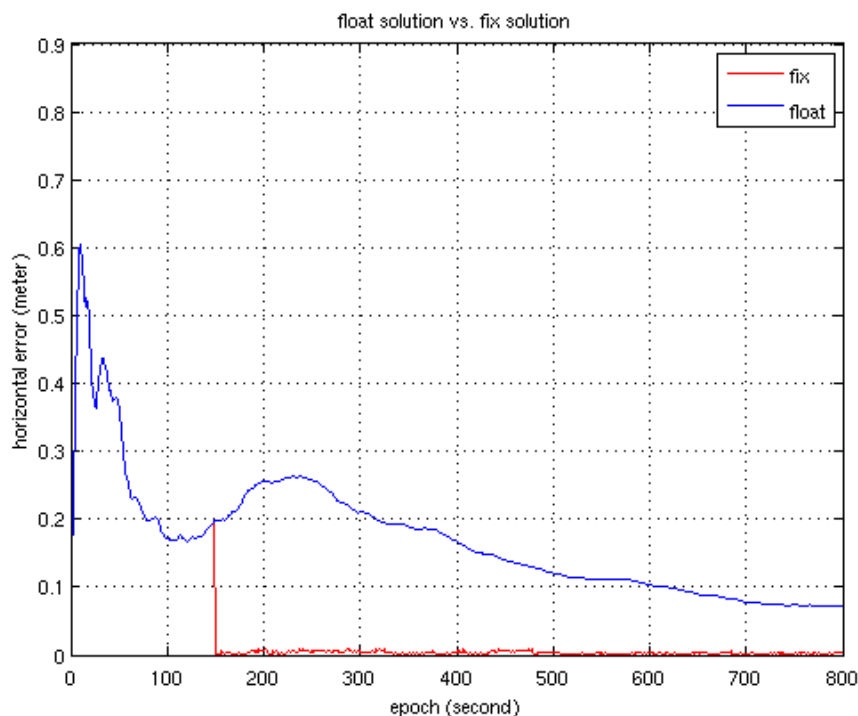
3. SPECIAL ISSUES RELATED TO PPP

3.1 Time-span of Continuous Observations

When operating in differential mode, it is in many cases possible to fix the carrier phase ambiguities to their correct integer values. This is possible due to sufficient cancellation of satellite and receiver hardware biases through the differencing process. However, working with undifferenced observations, as in PPP, it is not possible to resolve the carrier phase ambiguities meaning that the carrier phase ambiguities always has to be estimated in the adjustment in a so-called float solution, see e.g. Kouba (2003).

An example is visualized in figure 2 where horizontal errors from differential processing in kinematic mode are plotted for float and fix solutions respectively. Distance to the reference receiver is in this example less than 1 km. After approximately 150 seconds the processing software manages to fix the ambiguities and the accuracy of subsequent epochs are at the centimeter level. Due to a weaker geometry than in the fix solution, the accuracy of the float solution only slowly increases as a function of time.

Due to burden of carrier phase ambiguities, PPP being a float solution, needs a certain time span of continuous observations to meet high accuracy requirements. In some applications, e.g. positioning of airborne sensors, this can be accommodated by passive logging of observations for some time before and/or after the survey.



Figur 2 Typical kinematic accuracy for float and fix solution for short baselines.

3.2 Reference Frames

Coordinates estimated with PPP will be in the same global reference frame as the satellite orbits. When using orbits from IGS, estimated receiver coordinates are referred to the IGS realization of International Terrestrial Reference Frame (ITRF), currently ITRF2000, at the time of observation. However, in most mapping applications and in navigation the user would like to transform the ITRF2000 coordinates into local or regional frames such as the European Terrestrial Reference Frame 1989 (ETRF89). Plag et al. (2002) describes how coordinates in ITRF can be transformed to the Norwegian realization of ETRF89. Similar information regarding transformation from ITRF to national reference frames is available from most national mapping agencies.

3.3 Latency of Orbits and Satellite Clock Corrections

When processing with IGS orbits, satellite clock corrections and earth orientation parameters, a number of different products are freely available, see <http://igsceb.jpl.nasa.gov/components/prods.html>. The IGS products have different characteristics regarding latency, update rate, sample interval and accuracy. For high accuracy applications, the latency presently makes PPP a postprocessing option when using IGS products. It should be noted however that IGS is currently working towards real-time products, IGS (2002).

4. DEVELOPMENT OF A OPERATIONAL PPP SOFTWARE

The experimental university software ABSPOS was implemented at the Norwegian University of Life Sciences (formerly known as the Agricultural University of Norway) and used successfully in e.g. seafloor mapping projects, Ovstedal et al. (2002). The Hydrographic Survey of Norway carried out extensive testing of ABSPOS, Nesheim&Ofstad (2004) and implemented the software into their production line for seafloor mapping in 2004.

Effect	Method
Satellite antenna offset and phase center variations	Official IGS antenna calibrations
Satellite hardware biases	Official IGS calibrations, estimation of system specific effects.
Satellite yaw	Nominal model, user definable during eclipses and noon-turns, e.g. editing or stochastic correction.
Ionospheric delays	Ionosphere-free linear combinations
Tropospheric delays	Apriori models, estimation of residual effects
Receiver antenna offsets and phase center variations	Official IGS calibrations
System specific receiver hardware biases	Estimation
Solid earth tides	Model recommended by the IERS
Ocean loading	Model recommended by the IERS
Rotational deformation due to polar motion	Model recommended by the IERS

Table 1. How effects relevant to PPP is handled in TerraPos.

Due to practical considerations it was decided that commercial issues and new development would be better handled by a private company, and the Norwegian company TerraTec was chosen to develop a professional software. The new software TerraPos represents state of the art in PPP processing and is fully compatible with IGS and IERS (International Earth Rotation Service) models and conventions. Table 1 gives an overview over how some effects relevant to PPP is handled in TerraPos (Kjorsvik, 2006).

Table 2 shows typical positional accuracy obtained when processing dual frequency observations of high quality with TerraPos.

Dynamics	Duration (hours)	Horizontal (meter)	Vertical (meter)
Static	24	0.01	0.02
	6	0.02	0.04
	1	0.05	0.10
Kinematic	24	0.03	0.04
	6	0.03	0.05
	1	0.15	0.20

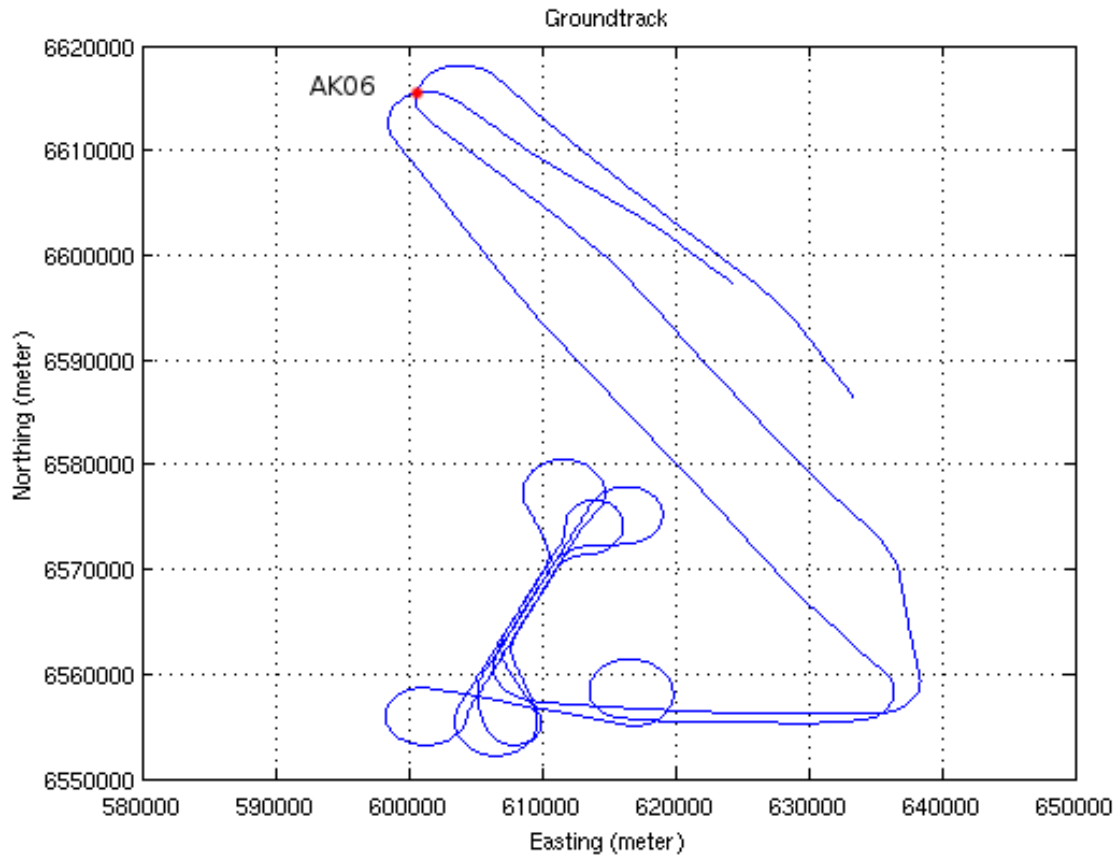
Table 2. Typical RMS of true errors when processing high quality observations with TerraPos.

In addition to seafloor mapping, the software is used in various applications as positioning of airborne sensors (aerial photogrammetry and laser scanning) and static survey of points.

4.1 An Example of Kinematic PPP processing.

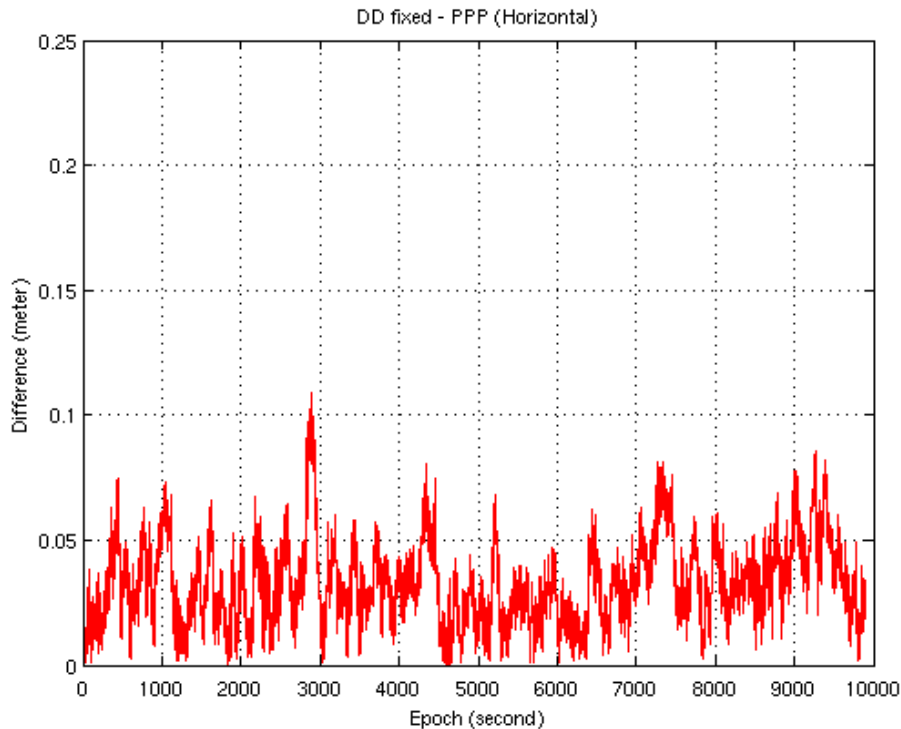
In direct referencing of airborne sensors like aerial cameras, GPS has to be supported by a Inertial Navigation System (INS) in order to obtain precise orientation parameters (position *and* rotation angles). A preferred method for calibrating a combined camera&GPS&INS system is to carry out photo missions over testfields with precise ground control points. Orientation parameters estimated by photogrammetric methods only is compared to orientation parameters estimates with the camera&GPS&INS system and differences are used as calibration values in subsequent photo missions.

Figure 3 shows the ground track from a calibration flight over testfield Fredrikstad in Norway. For this flight a reference receiver was situated at the site AK06, approximately 80 km from the testfield. In both the aircraft receiver and the reference receiver dual frequency GPS observations were recorded with an observation interval of 1 second. Kinematic trajectories were estimated by both a differential processing using the GPSROG-software (Ovstedal, 2000) and the PPP-software TerraTec (Kjorsvik, 2006). In order to enhance initialization of carrier phase ambiguities, the aircraft passed near the reference receiver before and after the actual photo mission. The differential processing was carried out as a fix-solution using the ionosphere-free linear combination as observable in the final processing. For the PPP processing, precise orbits, satellite clock corrections and earth orientation parameters were downloaded from IGS.



Figur 3 Trajectory of camera&GPS&INS calibration flight. A reference receiver was operating in AK06.

In figure 4 coordinate differences between horizontal coordinates estimated by differential processing and PPP are plotted as function of time. It should be noted that in this project the GPS receiver in the aircraft logged some additional observation after that the aircraft had landed so that the PPP processing could be carried out with 3 hours of continuous observations. A further expansion of the time span of observations would have increased the accuracy of the PPP solution.



Figur 4 Time-plot of differences between horizontal coordinates estimated with differential processing and with PPP.

For this dataset, coordinates estimated with differential- and PPP processing are consistent at approximately the 0.05 meter level.

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